D. W. KELLEY & Associates

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MIGRATIONS OF ADULT STRIPED BASS IN THE SACRAMENTO-SAN JOAQUIN ESTUARY IN RELATION TO WATER TEMPERATURE WITH EMPHASIS ON THE THERMAL NICHE HYPOTHESIS

by William T. Mitchell

INTRODUCTION

Tagging studies since the early 1950s have demonstrated that adult striped bass in the Sacramento-San Joaquin Estuary have an annual migratory pattern characterized in general by an upstream fall migration to the Delta, overwintering in Delta waters, dispersal throughout the Delta and Sacramento River to spawn in the spring, and summer migration back to the Delta and San Francisco Bay. While this general pattern has continued, tag returns have provided evidence of major changes in the extent of seaward migration. Chadwick (1967) concluded that migrations into San Francisco Bay and the Pacific Ocean from 1958 through 1964 were much greater than Calhoun (1952) had described in the early 1950s. In addition, many bass remained in San Francisco Bay through the winter. This pattern continued in 1965-1966, although a large percentage of the bass overwintered in San Pablo Bay (Orsi 1971). My analysis of tag return data from 1969 through 1985 revealed that in recent years bass have been using bay waters to a lesser extent than they did in the late 1950s and early to mid-1960s. In this report I describe these recent changes and examine historical changes in striped bass migrations in relation to changes in bay and Delta water temperatures, in an effort to test the applicability of the thermal niche hypothesis proposed by Coutant (1985).

METHODS AND DATA SOURCES

Tag return data by year, month, and location were furnished by the California Department of Fish and Game. The tagging methods during 1969-1985 were generally the same as those described by Chadwick (1967). Tagging was done in the western Sacramento-San Joaquin Delta and Sacramento River each spring. Only legal-sized fish were tagged (16 inches or over total length). Return data are based on angler recoveries of tagged fish within the first year after tagging. I divided the tag return data into two periods, 1969-1976 and 1977-1985, to evaluate apparent changes in striped bass distribution since the mid-1970s.

Table 1. A sample of water temperature (°C) data collected at approximately biweekly intervals at five stations in the Sacramento-San Joaquin Delta (Source: DWR Delta Water Quality Surveillance Program).

	Antioch	Emmaton	Rio Vista	Jersey Point	Twitchell Island
1971					
JUN 1-15	18	17	18	18	18
JUN 16-30	22	21	20	21	--
AUG 1-15	24	23	24	24	24
AUG 16-31	24	21	22	--	--
OCT 1-15	19	18	20	19	--
OCT 16-31	17	17	16	18	17
1975					
JUN 1-15	21	20	21	21	21
JUN 16-30	20	20	20	20	20
AUG 1-15	21	21	21	22	22
AUG 16-31	22	21	22	22	22
OCT 1-15	--	17	16	18	18
OCT 16-31	18	15	14	15	15
1978					
JUN 1-15	21	21	21	21	21
JUN 16-30	21	20	21	21	21
AUG 1-15	23	22	24	24	24
AUG 16-31	22	21	21	23	22
OCT 1-15	21	21	20	21	20
OCT 16-31	19	18	18	--	18
1981					
JUN 1-15	22	21	23	22	22
JUN 16-30	25	23	24	--	25
AUG 1-15	23	22	23	23	23
AUG 16-31	22	20	21	22	22
OCT 1-15	21	20	20	21	20
OCT 16-31	19	19	20	20	19

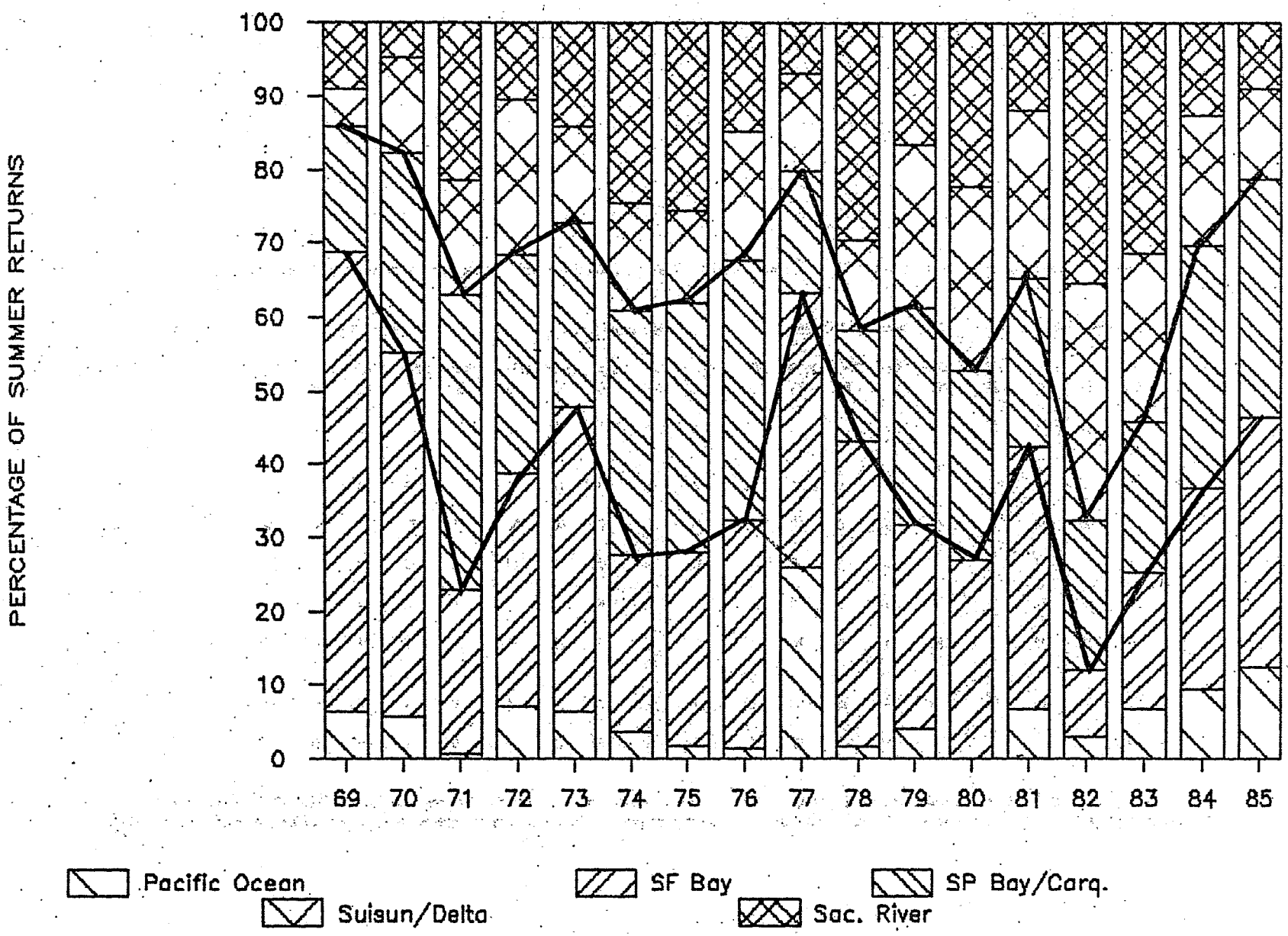

Figure 1. Annual variation in summer striped bass distribution based on first-year returns of fish tagged in the western Delta during spring, 1969-1985. The extent of seaward migration during 1969-1985 has been less than that which occurred during 1958-1961 and 1965-1966 (see Table 3).

Fall Returns: September-November

Fall returns indicate that changes in the extent and/or timing of upstream migration occurred between 1958 and the present. An increasing trend in the relative returns from San Francisco Bay between 1958 and 1964 (Chadwick 1967) continued in 1965-1967 (Orsi 1977) and reached a peak in 1974 (Table 3; Figure 2). Since then there has been a gradual decline in the returns from San Francisco Bay and a greater number of years when no tagged fish were recovered from ocean waters.

During the period 1977-1985, half the total fall returns were caught upstream of Carquinez Strait compared to an average of 20% during the earlier three periods (Table 3). In 1985 the distribution of the population appeared to be similar to that reported by Calhoun (1952) for the early 1950s when most of the tagged fish were recovered in Delta waters during the fall (Figure 2; Table 3). Thus tag returns provide evidence of a greater and perhaps earlier upstream migration in the fall of recent years. Alternatively, more fish may have remained in upstream areas during the summer and fall.

Winter Returns: December-February

Changes in the distribution of tagged striped bass caught during winter also reflect decreased utilization of bay waters in recent years (Table 3; Figure 3). During the period 1958-1961, a very large fraction of the population probably wintered in San Francisco Bay (Chadwick 1967). In 1965-1966 the population appeared to be concentrated in San Pablo Bay (Orsi 1972). Recent tag returns provide evidence that between 1969 and 1985 proportionately relatively fewer bass wintered in San Francisco and San Pablo Bays (Table 3). This was associated with over a two or threefold increase in the percentage of total returns from the Delta and Suisun Bay. The greatest difference occurred in recent years (1977-1985), when an average 70% of the total winter returns came from the Delta and Suisun Bay in contrast to 26% in the early to mid-1960s. In the winter of 1977, over 90% of the striped bass returns were caught in the Delta and Suisun Bay (Figure 3). As in fall, the major shift in winter distribution of the population began in the mid-1970s. The fraction of winter returns from San Francisco Bay dropped from 20%-30% in the early 1970s to less than 10% in 1975 where it has remained to the present (Figure 3). No ocean returns were reported after 1973.

Spring Returns: March-May

During spring, the upstream spawning migration of striped bass was indicated by a preponderance of tagged fish in the Delta and upper Sacramento River (Figure 4). Greater returns from the upper Sacramento River relative to San Francisco Bay returns are evidence of a general upstream shift of the spring population since the mid-1970s (Table 3). No tagged fish were

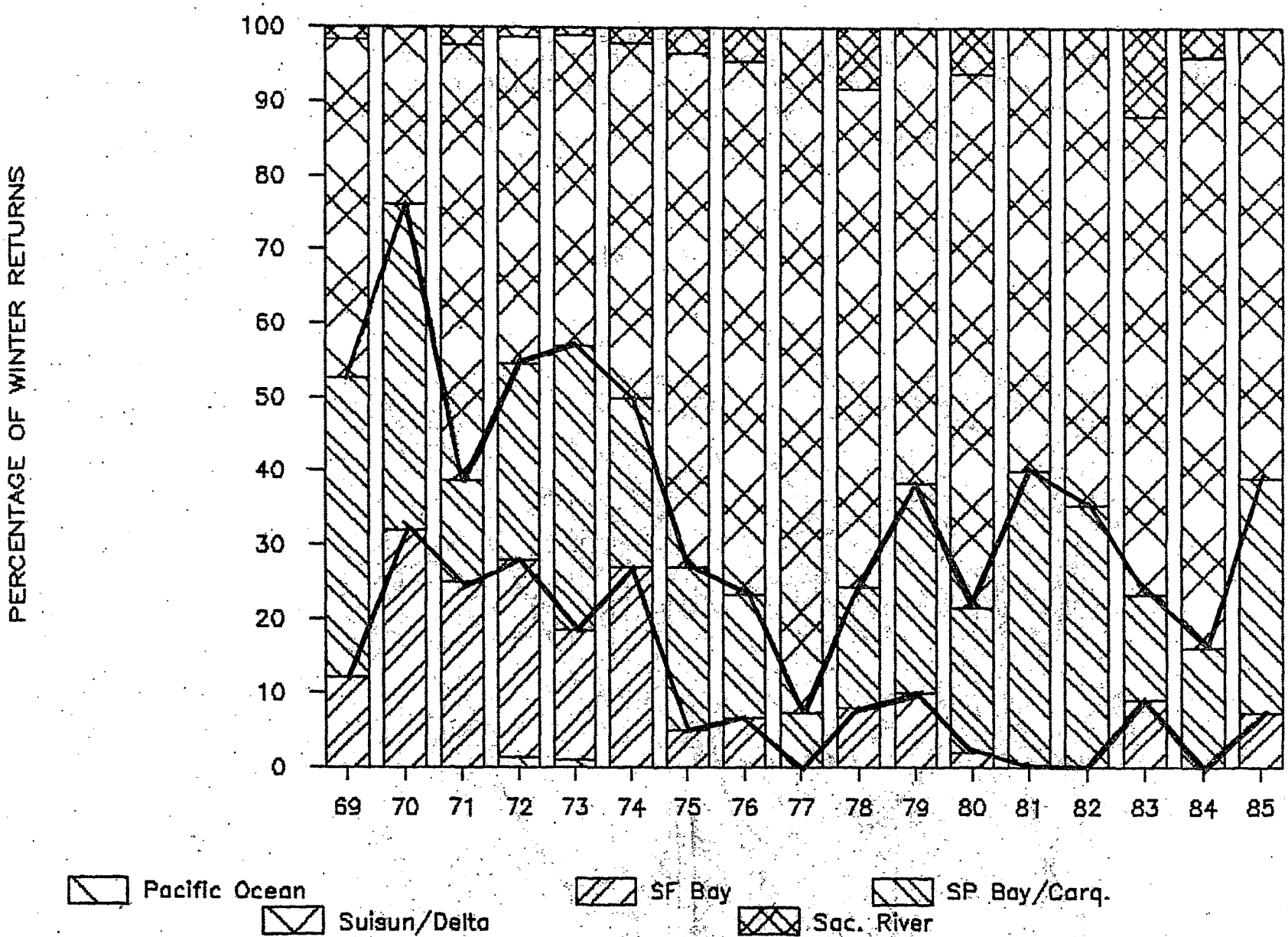

Figure 3. Annual variation in winter striped bass distribution based on first-year returns of fish tagged in the western Delta during spring, 1969-1985. As in fall, winter returns reflect a major upstream shift in striped bass distribution since 1975.

taken from San Francisco Bay in 1978, 1980, or 1984. Since 1977, the average fraction of returns from the Delta and upper Sacramento River has been 83%, which is equal to the proportion of spring returns reported by Calhoun (1952) for this area in 1950-1952 (Table 3). During the early 1950s, however, the population appeared to be concentrated in the Delta whereas now a greater proportion is recovered from the upper Sacramento River.

RELATIONSHIP BETWEEN STRIPED BASS MIGRATIONS AND TEMPERATURE

Coutant (1985) proposed the thermal niche-dissolved oxygen hypothesis as a basis for explaining the observed patterns of distribution and abundance of striped bass, including population declines in coastal waters and variable success of freshwater introductions. This hypothesis states that genetically-defined temperature and dissolved oxygen requirements of striped bass can restrict the amount of suitable habitat available to them and lead to population limitation through direct and indirect mechanisms that affect survival and fecundity. Coutant draws evidence from field observations of striped bass movements and distribution which suggest the existence of a thermal niche that shifts to lower temperatures as fish age. He defines a thermal niche for adult striped bass between 18° and 25°C (65°-77°F)--with a preferred range of 18° to 21°C (65° to 70°F).

Coutant cites accounts of variation in the degree of downstream migrations of striped bass in the Sacramento-San Joaquin Delta areas as further evidence of the thermal niche hypothesis. For example, the upsurge in catches of tagged striped bass in San Francisco Bay and coastal waters in the late 1950s (Chadwick 1967) coincided with higher ocean water temperatures than had occurred in the early 1950s when tag returns were concentrated upstream of San Pablo Bay (Calhoun 1952). In addition, he cites Radovich's (1963) finding of a close positive correlation between an "index of seaward migration" (developed from 22 years of Delta and San Francisco Bay catch data) and sea surface temperatures measured at La Jolla in southern California. That larger fish move farther downstream (Chadwick 1967; Orsi 1971) is also consistent with a size-dependent response to temperature.

Although Radovich provided evidence of greater downstream migrations of striped bass into bay and ocean waters in warmer years, there is no evidence that adult bass are avoiding waters cooler than 18°C (65°F) as suggested by Coutant. In fact, average summer and fall water temperatures recorded at the mouth of San Francisco Bay (Fort Point) were less than 61°F in 1958 and 1959 when large catches were first reported from San Francisco Bay and the Pacific Ocean (Figures 5 and 6). Furthermore, summer and fall catches from bay and ocean waters remained relatively high in the mid-1960s despite a return to

cooler pre-1958 temperature levels. Accordingly, Chadwick (1967) found that the magnitude of the ocean fishery as indexed by tag returns was not closely related to mean annual or mean summer sea temperatures from 1958 through 1964. Since 1965 water temperature at Fort Point has exhibited a general increasing trend although tag returns indicate that the relative abundance of striped bass in San Francisco Bay experienced a marked decline after reaching a peak in 1974 (Figures 5 and 6).

No clear relationship was apparent between water temperatures measured within the bay at Alameda and annual tag returns from San Francisco Bay, although some general observations are noteworthy. In contrast to Fort Point, Alameda temperatures during the summer are typically 2-3 degrees Fahrenheit above the lower limit of the thermal niche of adult striped bass as defined by Coutant (65°F) and typically drop 2-3 degrees Fahrenheit below the limit in the fall (Figure 7). In the late 1950s, however, average fall temperatures were relatively high (ca. 65°F) and tag returns from the bay were substantially higher than those reported in the early 1950s (Figures 5 and 7). This might lend support to Coutant's hypothesis, except that in the more typical (cooler) years that followed tag returns from San Francisco Bay remained high. In fact, the surge in fall tag returns between 1971 and 1974 (Figure 2) coincided with fall temperatures between 62° and 63°F (Figure 7). In 1980, 1981, and 1982, however, exceptionally low summer water temperatures were associated with relatively low returns from San Francisco Bay (Table 2).

Coutant suggested that migrations and distribution of adult striped bass in estuaries are controlled by seasonal and annual variation in temperature gradients between freshwater and saltwater. He cited Calhoun's observations of a downstream migration of larger fish from the Delta and Suisun Bay in the summer and return migration in the fall as evidence of a thermally-driven response to seasonal warming and cooling in the upper parts of the estuary. To examine the possible influence of Delta temperatures on recent migrations of striped bass, I compared average summer and fall water temperatures in the lower Sacramento River at Rio Vista and San Joaquin River at Twitchell Island with summer and fall tag returns from the Delta between 1969 and 1982.

No relationship between Delta returns and water temperature was apparent, but there was a general association between warmer fall water temperatures after 1975 and increasing fall returns (Figures 8, 9, and 10). While summer temperatures in the Delta showed little change between 1969 and the present (temperatures fluctuated around an average of 71°-72°F), fall temperatures increased in the drought years of 1976-1977, and between 1976 and 1981 averaged 66° compared with an average of 63°F between 1969 and 1975 (Figures 9 and 10). The major increases in fall returns occurred in 1976-1977, 1979, and 1981, the same years fall temperatures at Twitchell Island peaked at

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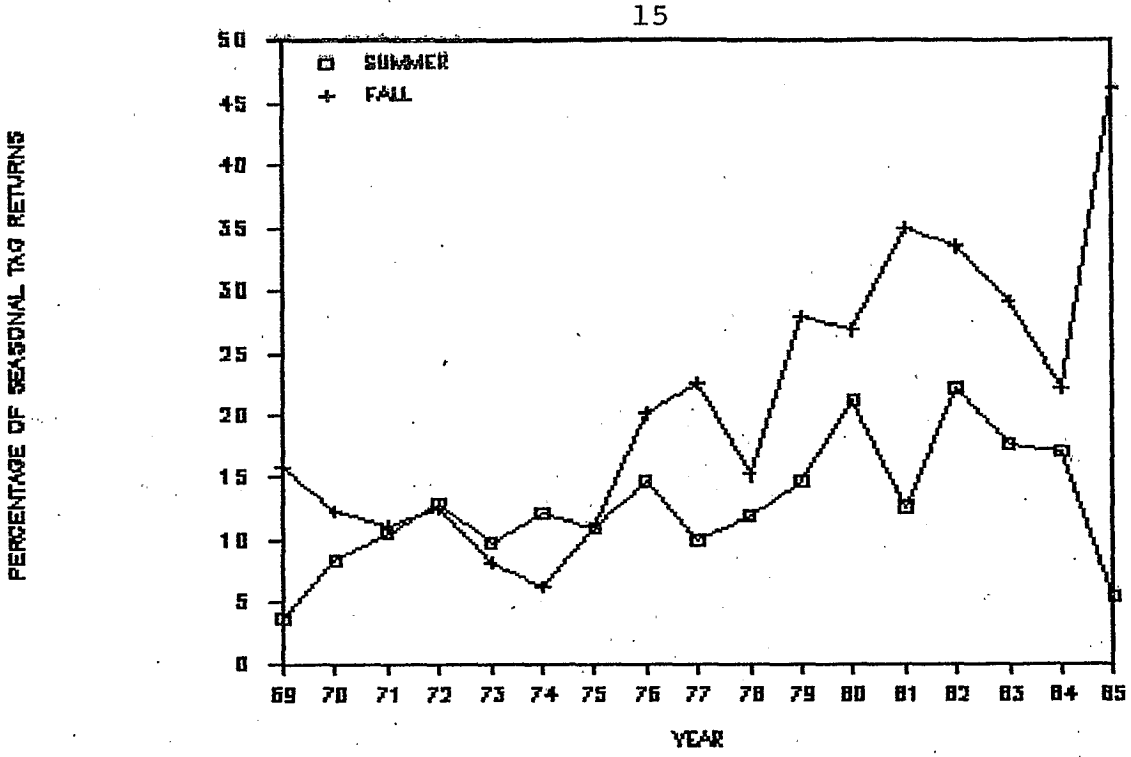

Figure 8. Summer and fall returns of tagged striped bass from the Delta in years 1969 through 1985. Values are percentages of total seasonal returns. A general increasing trend in summer and fall returns after 1975 suggests that post-spawning bass are utilizing Delta waters to a greater extent in recent years.

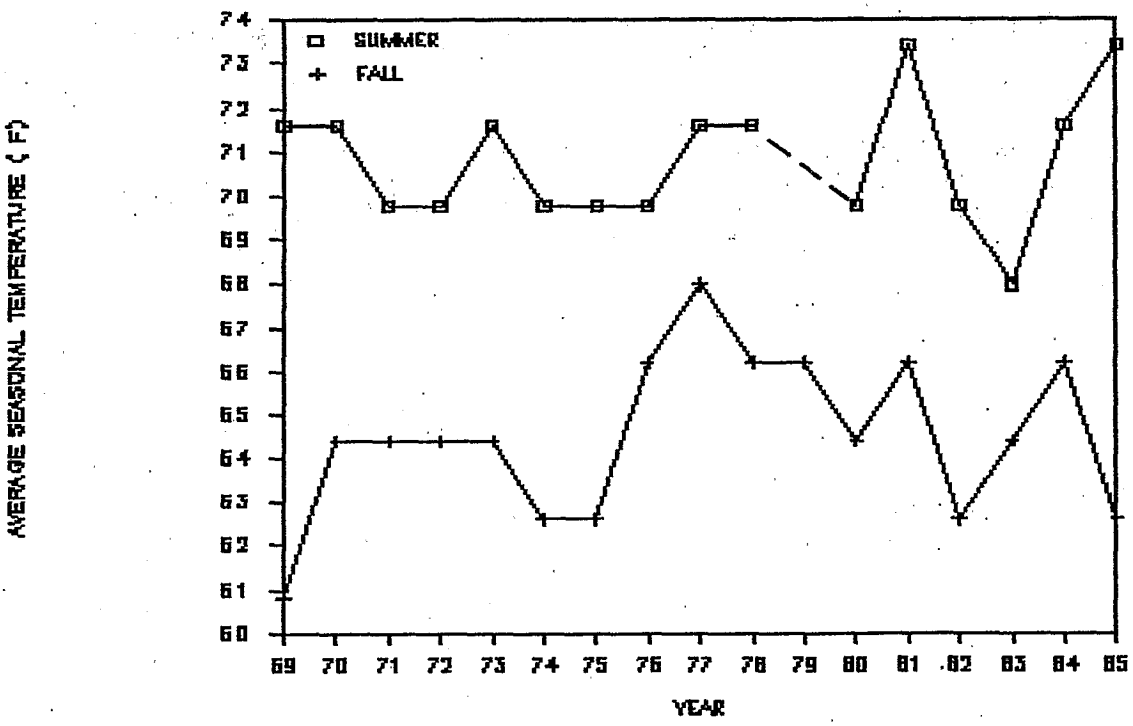

Figure 9. Average summer and fall temperatures in the lower Sacramento River-Delta at Rio Vista between 1969 and 1985. Fall water temperatures between 1976 and 1981 averaged 3-4 degrees Fahrenheit higher than fall temperatures between 1969 and 1975.

68°F. After 1981, average fall temperatures and fall bass returns declined. In 1985, however, fall returns from the Delta were the largest since 1969 yet were associated with temperatures comparable to the pre-1976 levels.

SUMMARY AND CONCLUSION

Recent changes in the distribution of returns of tagged adult striped bass in the Sacramento-San Joaquin system have provided evidence that migrations into San Francisco Bay decreased during the mid- to late 1970s and that this change was accompanied by an increase in returns from the Suisun Bay and Delta.

Coutant (1985) proposed the thermal niche-dissolved oxygen hypothesis as a basis for explaining the observed patterns of distribution and abundance of striped bass. His hypothesis states in part that the migrations and distribution of adult striped bass are strongly influenced by their requirement for temperatures within the range 18°-25°C (65°-77°F), and that restriction of suitable habitat in this range can limit survival, fecundity, and population size. To test the applicability of this hypothesis to the Sacramento-San Joaquin population, I compared tag return data from 1969-1985 and earlier periods with long-term water temperature data from San Francisco Bay and the Delta.

I found no evidence that adult bass are avoiding waters cooler than 18°C (65°F) as suggested by Coutant. Between the late 1950s and mid-1970s, a large fraction of the population occurred in San Francisco Bay during the summer and fall months when water temperatures near the mouth (Fort Point) generally ranged between (13°C) 56°F and (16°C) 60°F. Water temperatures inside the Bay (at Alameda) were warmer but no clear relationship between tag returns and temperature was apparent. Although the same was true for the Delta, there was a general association between warmer fall water temperatures and increasing Delta returns between 1976 and 1981.

There was no consistent relationship between tag returns and water temperature, and I found no reason to suspect that water temperature has strongly influenced migrations of adult striped bass in the Sacramento-San Joaquin Estuary.